



National Aeronautics and Space Administration

# Return to Flight: The Seven Elements of Flight Rationale

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# STS-114 Return to Flight

## Discovery of Marginalized Issues

- 2003: Acceptance of an unacceptable situation led to the Columbia disaster. The foam issue was rationalized as routine and expected and probably okay.
- 2004: Although catastrophic, only in retrospect was it obvious how badly the foam was mischaracterized.
  - The Challenger concept of Normalization of Deviance urged propulsion engineers to find what other problems may have been waiting to occur.
  - Propulsion engineers uncovered between 12 and 14 possibly marginalized issues that were not acting as intended by design.
- 2005: For the STS-114 Return to Flight (RTF), the engineers came up with seven steps, which were baselined in the Shuttle Program, as the way to approve technical issues for flight—the Seven Elements of Flight Rationale.
  - “These are good, solid systems engineering-type questions that you ask whenever there’s an issue that comes up where something’s not acting the way it was designed to.” –Bryan O’Connor



Figure 1. STS-114 Mission Commander checks Discovery's cockpit window in the Orbiter Processing Facility at KSC. Source: NASA.

# Seven Elements of Flight Rationale

## 1. Solid technical understanding

- Why are we making this change? What problem are we addressing? Do we know what we are giving up? How well do we understand the fix? Are the critical features inspectable? Is the process under control?
- Do we know how/why this condition occurred (impact, scrape, age out, moisture loss, residual stress, etc.)? Do we understand root cause? Did we use a fault tree? Do we understand the extent of the crack, high-density indication (HDI), damage, foreign object debris (FOD), etc.? Do we know what the foreign material is? What are the plausible contaminants and how could they be harmful?
- Do we understand how/why components with similar indications performed the way they did? Is there a fix/repair for this unit/article? Do we understand the repair process/condition? Are the generic design and process robust and in control?

## 2. Condition relative to experience base

- Have we dealt with this problem before? How is this the same? Different? Do we have flight or test history with this defect? With this repair? Other motors or programs? How are we the same? Different? Was the similar feature actually exercised in a test? What was the outcome?

# Seven Elements of Flight Rationale

## 3. Bounding case established

- What bounding scenarios (test, analysis, etc.) have been evaluated in the attempt to bound or envelope the issue (e.g. upper 3 $\sigma$  loads, lower A basis allowables, a specific worse hardware condition)?
- What assumptions were made? Where are they conservative? Not? Were all the failure modes addressed? Have we considered the “what if we’re wrong” scenarios?



Figure 2. The Orbiter Boom Sensor System undergoing final checkout and testing in the lab prior to installation on Discovery. The 50-foot-long sensor was one of the new safety measures for STS-114, equipping the orbiter with the ability to inspect the Shuttle's Thermal Protection System while in space. Source: NASA.

## 4. Self-limiting aspects

- Physical reasons why the defect or condition will not get worse than current state or degrade. Why can the condition never exceed the bounding case?
- Is the system failsafe or fault/failure tolerant? Are there built-in redundancies if the feature does fail? Are all the critical features/operations inspectable?

## 5. Margins understood

- What are the predicted margins for the discrepant or repaired part? Have they changed from baseline? What are the margins for the bounding case?
- Is the component/feature in an area of high or low thermal or structural margin? How far are we from a cliff?

# Seven Elements of Flight Rationale

## 6. Assessment based on data, testing and analysis

- Is the final assessment based on test data and analysis or on expert opinion and gut feel? Where do we actually have data? Where are we guessing? Was the test/measurement/analysis technique standard and proven or new?
- Do we understand all the assumptions that went into the assessment? Does the analysis/assessment rely on a series of dependent assumptions (where an error could propagate) or are there independent elements or blocks?

## 7. Interactions with other elements/conditions addressed

- Are there any known, compounding interactions with other issues, components, changes, etc.? How have the potential interactions been identified? How/when will they be addressed?

*Challenge something that's acting in a way we did not design it to act, even if it is in-family. Don't just accept in-family as a rationale.*

*After applying the seven steps to the post-Columbia issues, engineers were able to assure that there were no other marginalized issues concerning the propulsion systems.*

# Recommendations

## In Retrospect

- “There were a lot of other things we did during the return-to-flight period that were more root-cause kinds of things, like better communications and making sure that we had the ability to get other assets if we needed to have pictures on orbit, but the Seven Elements is the one that I remember the most.”

–Bryan O’Connor, August 3, 2011

- The response to both Challenger and Columbia went beyond the actual cause of the accident itself and looked for what other issues could be laying dormant. By adopting that same mentality, we will have a better chance in tackling these current challenges facing us as an Agency.
- By utilizing these “solid systems engineering-type questions” proactively, we can better understand, characterize and communicate the risks facing the Agency and place ourselves in a better posture for achieving Mission Success.



Figure 3. Mission Success: Discovery is being towed into the Orbiter Processing Facility bay 3 at KSC. Source: NASA.